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Review

Automatic and controlled processes and the development of addictive behaviors in adolescents: A review and a model

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Abstract

This paper presents a review and a model of the development of addictive behaviors in (human) adolescents, with a focus on alcohol. The model proposes that addictive behaviors develop as the result of an imbalance between two systems: an appetitive, approach-oriented system that becomes sensitized with repeated alcohol use and a regulatory executive system that is not fully developed and that is compromised by exposure to alcohol. Self-regulation critically depends on two factors: ability and motivation to regulate the appetitive response tendency. The motivational aspect is often still weak in heavy drinking adolescents, who typically do not recognize their drinking as problematic. Motivation to regulate use often develops only years later, after the individual has encountered serious alcohol-related problems. Unfortunately, at that point behavioral change becomes harder due to several neurocognitive adaptations that result from heavy drinking. As we document, there is preliminary support for the central elements of the model (appetitive motivation vs. self-regulation), but there is a paucity of research directly addressing these mechanisms in human adolescents. Further, we emphasize that adolescent alcohol use primarily takes place in a social context, and that therefore studies should not solely focus on intra-individual factors predicting substance use and misuse but also on interpersonal social factors. Finally, we discuss implications of the model for interventions.

Keywords: Implicit cognition; Executive functions; Alcohol; Adolescence

Contents

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1. Introduction

This paper proposes a model for the development of addictive behaviors in (human) adolescents, with a focus on alcohol, the most popular drug among teenagers in many parts of the world (NIAAA, 2005). In most general terms, the model proposes that addictive behaviors develop as the result of an imbalance between two systems: (1) an appetitive, approach-oriented system that becomes sensitized with repeated alcohol use, leading to relatively automatic action tendencies to approach alcohol (or other drugs), and (2) a regulatory executive system that is not fully developed until young adulthood and that is compromised by sufficient exposure to alcohol. In addition, there is evidence that the controlled regulatory processes are strongly weakened by the acute effects of alcohol, whereas more automatic, approach-oriented processes are not and can even be primed by drinking alcohol. Self-regulation does not only depend on *ability* to inhibit appetitive tendencies, an individual should also be *motivated* to do so. Usually, the motivation to regulate addictive behaviors is low in adolescents, because adolescents often do not recognize their alcohol and drug use as problematic. As our review will show, there is preliminary support for both central elements of the model (appetitive motivation vs. self-regulation), but it should be emphasized that there is a paucity of research directly addressing neurocognitive mechanisms involved in the development of addictive behaviors in (human) adolescents. The model is conceptually related to several other recent models of addictive behaviors that posit the importance of both sensitized reward processes and compromise inhibitory control as a result of prolonged alcohol or drug abuse (e.g., Jentsch and Taylor, 1999; Robinson and Berridge, 2003; Volkow et al., 2003; Lubman et al., 2004; Dawe et al., 2004). The model we present differs from those earlier reviews primarily in terms of the research tradition on which it is based. Specifically, whereas previous reviews were based on the neurobiological animal literature (e.g., Jentsch and Taylor, 1999; Robinson and Berridge, 2003), human neuroimaging and neuropsychological studies (e.g., Volkow et al., 2003; Lubman et al., 2004) and personality research (e.g. Dawe et al., 2004), the present model is primarily based on behavioral and electrophysiological research in human adolescents and young adults, with a focus on recent studies that have tried to assess relatively automatic cognitive motivational processes. Throughout the paper, where possible, we attempt to link the concepts and findings to underlying neurobiological mechanisms and models. We also devote attention to individual differences in relation to different aspects of the model, concentrating on data in which high-risk individuals like children of alcoholics (COAs) are compared with low risk controls. Intra-individual factors such as sensitized, appetitive response systems and a dysfunctional regulatory system are emphasized, but it is recognized that adolescent alcohol use is typically contextualized in social interactions in peer groups. Finally, we discuss implications of the model for intervention.

2. Appetitive motivation

2.1. Explicit measures of appetitive motivation

Much research has been focused on the prediction of alcohol use with explicit, self-report measures of appetitive motivation to consume alcohol. The pioneering work of Goldman and Brown and their colleagues on alcohol expectancies (Brown et al., 1980; Goldman et al., 1999), and the work by Cooper and colleagues on drinking motives (Cooper, 1994; Cooper et al., 1995), are key examples of this approach. The general idea in these approaches is that individuals differ in their expected reinforcement from alcohol use and that the more an individual expects positive, beneficial effects, the more he or she will drink (cf. Cox and Klinger, 1988). Positive expectancies and motivations to use alcohol are highly correlated (e.g. Cooper et al., 1995), and some have interpreted this as evidence that the two constructs are closely related (Goldman et al., 1999; Wiers et al., 2006a; but there is some evidence that motives are a more proximal predictor of alcohol use than expectancies, e.g., Cooper et al., 1995). Three basic types of explicit alcohol-related cognitions have been distinguished on the basis of basic learning theory principles: Positive reinforcement (i.e., that alcohol use will produce positive outcomes), negative reinforcement (i.e., that alcohol use will alleviate negative affect), and negative expectancies (i.e., that alcohol use will produce negative outcomes). Whereas both positive and negative reinforcement cognitions are associated with increased drinking, negative expectancies serve to inhibit drinking (Goldman et al., 1999; Wiers et al., 2006a). Similarly, some motives to abstain or moderate drinking are associated with reduced alcohol use, especially those associated with religious or cultural proscriptions (Chassin and Barrera, 1993; Maggs and Schulenberg, 1998; Nagoshi, et al., 1994; Reeves and Draper, 1984; Stritzke and Butt, 2001). However, some stated reasons for abstaining from or moderating drinking are, paradoxically, related to increased levels of consumption and problems (Collins et al., 2000; Greenfield et al., 1989; Slicker, 1997), presumably because they index aspects of dependence (e.g., loss of control and inability to abstain). Alcohol expectancies and motives are excellent correlates of alcohol use and problems in cross-sectional research (i.e., when both alcohol use and expectancies/motives are assessed at the same time), in some studies predicting up to 50% of variance (Goldman et al., 1997, 1999; Wiers et al., 1997). However, in prospective studies (i.e., when expectancies/motives are used to predict future alcohol use) the predictive power of expectancies and motives is much smaller (Jones et al., 2001; Goldman et al., 1999; Goldman and Darkes, 2004). Moreover, once the variance associated with previous behavior (i.e. typical alcohol use) is statistically controlled, explicit expectancies and motives predict little unique variance in drinking behavior (Bot et al., 2005a; Engels et al., 2005a,b; Goldman and Darkes, 2004; Sher et al., 1996; Stacy, 1997). However, the ability to predict prospectively, over and above previous drinking, increases with extended intervals between measurement occasions (Sher et al., 1996; Sher and Wood, 1997).

2.2. Implicit measures of appetitive motivation

More recently, researchers have begun to use more indirect or implicit measures to study cognitive motivational processes in alcohol and drug use. We broadly distinguish between two classes of implicit measures: those that assess an *attentional bias* for alcohol or drugs, and those that assess *implicit memory associations* (Wiers and Stacy, 2006; Wiers et al., 2006b). Before introducing these classes of measures, it should be noted that the term “implicit cognition” is used both in relation to assessment and to the underlying processes (De Houwer, 2006; Fazio and Olson, 2003). The term “implicit” is sometimes used as an equivalent for the term “indirect” when referring to measurement techniques (Fazio and Olson, 2003). When one uses an implicit or indirect measure to assess an attitude or motivational tendency, the attitude or motivational tendency is indirectly inferred from behavior as opposed to being measured via self-report (e.g., asking people why they use alcohol or drugs or what outcomes they expect from their use). De Houwer (2006) argued that not only can measurement *procedures* be defined as implicit, but so too the *outcomes* of such procedures (i.e., what is measured). In this sense, the term “implicit” refers to a number of functional properties that largely but not fully overlap with “automatic” (see Moors and De Houwer, 2006). Importantly, although “implicit” has sometimes been equated with “unconscious”, there is little evidence for most implicit measures used that people are not aware of what is measured (De Houwer, 2006; Gawronski et al., 2006). However, there is evidence that implicit measures are harder to fake than explicit measures; that scores on implicit tests have unique power to predict spontaneous behaviors; and that people may be unaware of the influence of their implicit associations on their behavior (De Houwer, 2006; Gawronski et al., 2006). For our purposes here, the crucial aspect of implicit measures is that they provide the researcher with a measurement of the to-be-measured construct in a relatively automatic way, which we believe may better capture the implicit processes that underlie real-life behaviors (addictive behaviors, in this case) than do explicit measures. Note that our use of the term “implicit” refers to “relatively automatic assessment” of cognitive motivational processes and not to the stricter definitions used in the literature on implicit learning (e.g. Shanks and St. John, 1996) and unconscious perception (e.g. Merikle and Daneman, 1998). Our use of the word implicit is closely related to definitions from research on implicit memory, which includes cases where verbal contents can come to mind (in fact, memory cannot be revealed in many tests unless it does come to mind). Yet many studies have shown that verbal contents can come to mind in the absence of conscious or deliberate recollection (see Stacy and Wiers, in press). In what follows, it may be assumed that the implicit measure was *not* unconscious in the sense that participants were not aware of what is measured (De Houwer, 2006; Gawronski et al., 2006), unless explicitly stated that this was the case.

Many researchers have also proposed a distinction between implicit and explicit underlying *processes*. The general idea is that implicit processes are spontaneous, fast and can sometimes occur outside of conscious awareness, whereas explicit processes are deliberate, slow and require conscious awareness (Evans, 2003; Greenwald and Banaji, 1995; Kahneman, 2003; Smith and DeCoster, 2000; Strack and Deutsch, 2004). Recent models have proposed that the fundamental difference between the two systems is that the implicit (or impulsive) system works through associational mechanisms only, while the explicit (or reflective) system works through propositional processes, which use elements of the same associative “database” as employed by the implicit system (e.g., Gawronski and Bodenhausen, 2006; Strack and Deutsch, 2004). This difference is important: an association is “always true” once it is triggered, but a proposition can be true or false. To give an example, one can have a strong association between alcohol and sex, while knowing at the explicit level that one does not become sexier after drinking alcohol. Importantly, negations are the domain of propositional knowledge. This has implications for prevention: when we teach youth that alcohol does *not* make you sexier, it is likely that the “not” label attached to the association between alcohol and sex erodes over time, leaving a stronger association between alcohol and sex as the ironic, unintended result of this intervention (Deutsch and Strack, 2006; Krank and Swift, 1994). Hence, intervention programs that focus on negative statements (e.g. “just say no”), may have ironic effects. This may be one of the reasons why one of the most often-used intervention programs (DARE) has consistently been found to be ineffective or even counterproductive (Lynam et al., 1999).

Given these developments in basic cognitive and memory research and the fact that addictions strike many as a prime

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example of an irrational behavior, it is not surprising that many researchers have recently formulated dual process models for the development of addictive behaviors. These models differ in their level of description and primary sources of inspiration: neurobiology (e.g. Yin and Knowlton, 2006; White, 1996); neuropsychology (e.g. Bechara et al., 2006); cognitive psychology (e.g. Evans and Coventry, 2006), and social psychology (e.g., Deutsch and Strack, 2006). The models also differ in the exact nature and number of systems proposed. However, at a more general level, all of these models describe at least two semi-independent systems: a fast associative "impulsive" system, which includes the automatic appraisal of stimuli in terms of their emotional and motivational significance that works through associations, and a slower "reflective" system that includes the controlled processes associated with conscious deliberations, emotion regulation and expected outcomes in propositional format. Finally, it is important to note that there is not a one-to-one relationship between implicit measures and implicit processes. In fact, recent studies indicate that often-used implicit measures such as the Implicit Association Test (IAT, Greenwald et al., 1998) partly tap into automatic processes and partly into controlled processes (e.g., Conrey et al., 2005). Still, they appear to better tap into the automatic processes involved in addictive behaviors than explicit measures such as questionnaires because they are unlikely to involve self-perceptions of behavior.

2.2.1. Attentional bias

A number of tasks have been developed in recent years to assess the extent to which drug-related cues capture or direct attention in drug users. Although the specific mechanisms tapped by these tasks tend to differ somewhat, the underlying principle guiding their use is the thesis that drug use and abuse episodes are set in motion via attention being directed to drug-related cues in the environment (Robinson and Berridge, 2003). However, it should be noted that the extent to which such attentional biases precede problematic alcohol and drug use or result from alcohol and drug involvement is as yet unclear (cf. De Jong et al., 2006; Field and Eastwood, 2005; Wiers et al., 2004, 2006b).

The best known test of drug cue-related attentional bias is the drug-Stroop test. As in the classical Stroop test (Stroop, 1935), the task of the participant in the drug-Stroop test is to name the color of words presented on a computer screen (or classically on a card) while attempting to refrain from reading the color words themselves. Substance abusers do this more slowly for words that are related to their substance of abuse (e.g. "beer" is color-named more slowly than "barn", among alcohol abusers). This "drug-Stroop" effect has now been demonstrated for many drugs of abuse (see for a recent review, Cox et al., 2006a,b). Basic research on attentional mechanisms distinguishes between different components of attention, including initial orienting to a stimulus and a later disengagement process (Field et al., 2006). The drug-Stroop test appears to primarily tap into the slower and more controlled disengagement process which is thought to be related to subjective craving (Stormark et al., 2000; Cox et al., 2006a,b).

Other tests of attentional bias may better tap into the early orienting aspect of attention, such as the visual probe task (Field et al., 2006). In this test, two pictures are shown simultaneously on a computer screen, one drug-related and the other not. After a brief interval these pictures disappear and a target stimulus that the subject must identify appears behind either the drug-related picture or the neutral picture. Drug abusers have often (but not always) been found to detect the target stimulus more quickly when it appears behind the drug-related picture compared to the neutral picture (e.g., Lubman et al., 2000; Townshend and Duka, 2001). This finding suggests that drug-related cues capture early selective attention in drug abusers, which facilitates responding to a target appearing in the same location. Other promising tests of attentional bias also have been developed, such as the flicker paradigm for inducing change blindness (Jones et al., 2002, 2003a,b). During this task, a display with different objects (alcohol-related and neutral) is presented for 250 ms on a computer screen. Then a mask is briefly presented, after which the initial visual scene is presented again for 250 ms with one object changed. This object can be alcohol- (or drug-) related or not. This sequence is repeated until the participant detects the changing object. Jones et al. (2003a,b) found that heavy drinkers detected an alcohol-related change faster than a neutral change, a difference that was not seen in light drinkers. Jones et al. interpreted this result as evidence that heavy drinkers' attention is automatically grabbed and captured by alcohol-related cues, making it easier for them to detect changes associated with such cues and harder to detect changes in the neutral stimuli. Comparable results have been found for problem drinkers vs. social drinkers (Jones et al., 2006). As yet, we know of very little research in which alcohol- and drug-related attentional bias in adolescents has been studied (see Zack et al., 2001, for an exception), let alone the development of attentional bias in relation to the development of alcohol or drug use. This clearly is an important issue for further research, as is the question of to what extent attentional bias is a causal factor in (or a close correlate of) the development of addictive behaviors (cf. De Jong et al., 2006; Field and Eastwood, 2005; Wiers et al., 2004, 2006b). This remains to be determined by experimental manipulation. A recent study presented suggestive evidence for a causal role of attention in craving: when attention of heavy drinkers was trained toward alcohol pictures an increase in craving and drinking was found and this was not the case in heavy drinkers in whom attention was trained away from alcohol (Field and Eastwood, 2005, see also Wiers et al., 2006b).

2.2.2. Implicit memory associations

There are two classes of measures that are used to assess implicit memory associations (note that "implicit" again refers to relatively spontaneous and automatic, not to "unconscious"): open ended memory association tasks and reaction time (RT) tasks. Stacy and colleagues have developed a variety of memory association tasks using indirect assessments that do not mention the target behavior directly (Ames and Stacy, 1998; Stacy et al., 1996; Stacy, 1997). With these measures, participants are asked to give their (time-limited) first association to a variety of cues

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chosen to implicitly activate memory associations associated with repeatedly performed behaviors (e.g., alcohol or drug use). These cues are either alcohol- or drug-related or not (e.g., Friday night vs. Thursday morning) and can consist of ambiguous words (e.g., draft), ambiguous phrases referring to affect (e.g. feeling good), or global situations (e.g. Friday night). Cues can also be combined (e.g. Friday–Night, feeling good……, the task is to fill in the first behavior one thinks of) to provide a more specific context for alcohol- and drug-related associations. In all cases, the indirect tests of word association used by Stacy and colleagues are modeled after indirect tests used in more basic research, which has demonstrated that they are capable of measuring associations in memory and an implicit, conceptual form of memory (see for a review and theoretical background, Stacy et al., 2006). These indirect tests of word association also allow for a measure of cognition capable of assessing relative cognitions in competition with alternatives. Importantly, Stacy (1997) demonstrated that the extent to which participants' spontaneous associations to ambiguous cues were alcohol or drug (marijuana) related, was the best predictor of alcohol and marijuana use in a prospective study after controlling for previous use, relative to other (explicit) measures. This prospective finding for alcohol was recently replicated by Kelly et al. (in press). A variety of studies among at-risk youth, college students, and drug offenders have now demonstrated the motivational relevance of the associations provided on these associative memory tasks in the prediction of alcohol and marijuana use, while controlling for a variety of potential confounders (e.g., Ames et al., 2006; Ames and Stacy, 1998; Stacy, 1997; Stacy et al., 1996). In addition, in one study among at-risk youth, associative memory was found to mediate the predictive effects of sensation seeking on alcohol and marijuana use (Ames et al., 2005). Word association tests have been found to be among the most useful assessments of association in basic memory research (e.g., Nelson and Goodmon, 2002; Nelson et al., 2000).

Wiers and colleagues have assessed memory associations through RT-tests, primarily using adapted versions of the Implicit Association Test (IAT, Greenwald et al., 1998). The IAT is a timed classification test, where 2 target categories (e.g. alcoholic drinks vs. soft-drinks) are sorted in different combinations with two attribute-categories (e.g. positive vs. negative valence). Participants' task is to classify stimuli (words or pictures) as fast as they can, using two classification rules with two opposing response buttons. Participants first learn one rule (e.g. press left when the stimulus presented is an alcoholic drink and right when the stimulus is a soft-drink). They then learn the other classification rule (e.g. press left when the stimulus presented is a negative word and right when it is a positive word). Then the two rules are combined: press left when the stimulus is either an alcoholic drink or a negative word and right when the stimulus is either a soft-drink or a positive word. After this first combination phase, participants learn a reversed version of one rule (e.g., press left when the stimulus presented is positive and right when it is negative), followed by the other combination (press left when the stimulus is either an alcoholic drink or a positive word and right when the stimulus is either a soft-drink or a negative word). The IAT-effect is the difference in reaction time between the one sorting condition (i.e. alcohol/negative vs. soft-drink/positive) and the other sorting condition (alcohol/positive vs. soft-drink/negative). (The best way to understand the IAT is to try it out, see www.implicit.harvard.edu).

Wiers et al. (2002) combined alcoholic drinks and soft-drinks with two basic emotional dimensions (Lang, 1995): positive–negative (valence) and arousal–sedation (arousal or activation). Perhaps surprisingly, they found much faster reaction times for the combination alcohol-negative (and soft-drink/positive) than for the combination alcohol-positive (and soft-drink/negative), suggesting strong negative alcohol associations in both heavy and light drinkers (faster reaction times for one sorting condition over the other sorting condition is interpreted as a stronger association in memory for the faster condition, Greenwald et al., 1998). This finding contrasted with the explicit positive attitudes of the same participants (Wiers et al., 2002). Subsequently, other studies using similar IATs have replicated this result (De Houwer et al., 2004; Wiers et al., 2005). The question arising from these consistent counterintuitive findings was whether the negative associations with alcohol found with the IAT represent something meaningful or an artifact of the IAT measurement procedure (e.g. De Houwer, 2002; Rothermund and Wentura, 2004). For example, since the IAT is a relative measure, the repeated finding that alcoholic drinks and negative words are sorted faster together, could also be due to an association in the opposite sorting condition (i.e., soft-drink and positive). Further, it is conceivable that heavy drinkers hold both positive and negative associations with alcohol, which cannot be assessed with a bipolar measure comparing positive and negative associations. A third problem with the interpretation of IAT-effects is that they may reflect differences in salience between the categories (Rothermund and Wentura, 2004). In case two salient categories are sorted together (e.g. alcoholic drinks and negative words), this may result in faster reaction times, irrespective of the actual memory associations. To test these alternative explanations, Houben and Wiers (2006a) tested a series of unipolar IATs, in which participants sorted alcoholic drinks together with positive, negative, arousal and sedation words (in balanced order, all in comparison with different matched neutral words). Half of the participants received soft-drinks as the opposite target category (as in previous work) and the other half of the participants received animals as irrelevant contrast category. In addition, half of the participants received the word "alcohol" as the relevant target condition, the other half the word "beer". The reason for this manipulation was that the word "alcohol" may have more negative connotations than "beer", because anti-alcohol campaigns typically use the word alcohol, while positive advertisements typically use a drink-category like beer. The target categories used (alcohol/beer × soft-drink/animals) only significantly influenced the results for the associations with negative valence. Importantly, in all four conditions, alcoholic drinks were sorted fastest with negative valence (large effect size) than with neutral valence. In addition to the strong negative alcohol associations observed, participants

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demonstrated moderately strong positive associations with alcohol. Similarly, both unipolar alcohol-arousal associations and sedation associations were found, with the arousal associations being stronger. In two separate studies, it was demonstrated that figure–ground asymmetries, as assessed with a separate visual search task (Rothermund and Wentura, 2004) could partly but not fully account for the strong negative alcohol associations found with the IAT (Houben and Wiers, 2006a, study 2; Houben and Wiers, 2006b), and not for the alcohol-arousal associations (Houben and Wiers, 2006a). Together, these findings replicate and extend the earlier findings regarding alcohol associations assessed with the IAT (Wiers et al., 2002, 2005): heavy drinkers hold both negative and positive alcohol associations. In addition they hold both arousal and sedation associations with alcohol (see below).

The interpretation of the now often reported strong negative associations with alcohol using the IAT is not clear at this moment. This finding appears to be partly but not fully due to specific measurement issues of the IAT (Houben and Wiers, 2006a,b). A meaningful interpretation could be that original negative associations with alcohol and other drugs that are commonplace in children (e.g., Wiers et al., 1998a) remain present in older adolescents and adults, and that more positive and arousal-related associations that adolescents and adults report develop next to the negative associations, creating (implicit) ambivalence (Houben and Wiers, 2006a; Rudman, 2004; Wiers et al., 2006a; cf. Wilson et al., 2000). Preliminary tests with other measures support the idea that alcohol has both strong positive and negative associations (De Houwer et al., 2004; De Jong et al., in press), as has been found for other ambivalent attitude objects (De Liver et al., in press).

On the arousal dimension, Wiers and colleagues have repeatedly found that heavy but not light drinkers associate alcohol with arousal, and that this association predicts alcohol use and problems, both cross-sectionally (Houben and Wiers, 2006a) and in a one month prospective study (Wiers et al., 2002 — in the latter study implicit associations predicted unique variance in drinking behavior above the explicit predictors, both did not after controlling for previous drinking). We hypothesized that alcohol-arousal associations could reflect the sensitization of the impulsive emotional system, as has been found in animal research (Robinson and Berridge, 2003). Note that the same has been hypothesized for other implicit measures of appetitive motivation, i.e. alcohol-approach associations (Palfai and Ostafin, 2003) and for a drug-related attentional bias (e.g. Franken, 2003). In a recent study, we tested whether alcohol-arousal associations in heavy drinkers (assessed with a unipolar IAT as in Houben and Wiers, 2006a) would reflect a heart-rate increase directly after rapid consumption of a large dose of alcohol (a putative measure of the psychomotor stimulant effects of alcohol, Conrod et al., 2001). This was not the case: we found a *negative* correlation between alcohol-arousal associations and heart-rate increase after alcohol consumption (Van den Wildenberg et al., 2006). This finding suggests that the alcohol-arousal associations most likely do not reflect an actual arousal response after drinking alcohol. Other evidence suggests that they reflect anticipatory appetitive arousal: arousal associations predicted cue-induced craving (Wiers et al, in Krank et al., 2005) and the same has been reported for alcohol-approach associations (Palfai and Ostafin, 2003). Together, these findings suggest that the alcohol-arousal and alcohol-approach associations more likely reflect a relatively automatic appetitive response to alcohol than a sensitized psychomotor stimulant response following alcohol consumption. But clearly more research is needed relating automatic associations to physiological responses to alcohol.

Finally, with respect to the assessment of approach action tendencies, it should be mentioned that a new measure has been employed recently, the Stimulus–Response Compatibility task (SRC). This test involves the approach or avoidance of a drug-related stimulus on the screen of a manikin (a matchstick figure of a human being) which either approaches or avoids the drug or neutral stimulus (Mogg et al., 2003). In one experimental block participants are requested to approach smoking stimuli by moving the manikin toward the smoking picture (the manikin appears under or above the picture) and to avoid neutral pictures. In the other experimental block this contingency is reversed (i.e. avoid smoking, approach control pictures). Reaction times for both response-assignments are compared. With this measure it was found that smokers were relatively fast to approach smoking cues in comparison with non-smokers (Mogg et al., 2003; Field et al., 2005b) and this was related to attentional bias and urge to smoke (Mogg et al., 2003).

The studies discussed so far have assessed the implicit associations of light and heavy drinking students; in our own studies the majority of participants have been 18 and 19 year-olds (note that in The Netherlands the legal drinking age is 16). Hence, even though the majority of participants can be categorized as “older adolescents”, the studies were not focused on adolescent drinkers per se. Recently, we have begun studying implicit associations in younger adolescents. Thush and Wiers (in press) assessed a variety of the IAT (Single Target IAT) in young adolescents (12–16 year-olds). In line with the model presented here, they found that in boys, implicit arousal associations positively and that explicit negative expectancies negatively predicted binge-drinking one year later. In a parallel study in the US and in The Netherlands, high-risk youth performed both some of the memory association measures developed by Stacy and colleagues and varieties of the IAT. Results from the US study (Ames et al., in press) indicate that marijuana use was predicted by word associations and by marijuana-excitement associations assessed with the IAT (combining positive and arousal words and contrasted with neutral words). Hence, preliminary findings from quite different implicit methods of assessing memory associations in youth support the idea that relatively spontaneous memory associations play a role in the development of alcohol and drug use in adolescence (see also Kelly et al., in press). This clearly constitutes an important domain for further research.

2.2.3. Psychophysiological measures of appetitive motivation

Psychophysiological measures can also be used to indirectly assess appetitive motivational processes. These measures are also implicit in the sense that they infer a motivational state from an experimental procedure, rather than asking participants to reflect upon their motivation (cf. De Houwer, 2006; Wiers and Stacy, 2006). For example, eye-movement registration has been used to assess direction of visual attention toward drug cues (Field et al., 2004a,b, 2006; Mogg et al., 2003). There is evidence that other psychophysiological measures also reflect appetitive reactions, such as the modulation of the startle response (Mucha et al., 2006). This measure has been used to obtain a psychophysiological index of the affective valence of stimuli: pleasant stimuli attenuate the startle response, whereas unpleasant stimuli enhance the startle response (see Lang et al., 1990). Most studies have reported attenuated startle responses in response to drug cues, suggesting appetitive responses (Mucha et al., 2006), and interestingly, this measure sometimes dissociates from subjectively reported reactions (e.g., alcoholics have been found to subjectively report avoidance reactions, while their startle potentiation indicated an appetitive response; Grüsser et al., 2002).

Measures of brain functioning such as the electroencephalogram (EEG) can also provide useful indirect indices of appetitive and aversive motivation. Numerous studies have shown that frontal cortical areas are asymmetrically active in the presence of approach-related (left-frontal) and withdrawal-related (right-frontal) stimuli, and that this asymmetrical activity predicts approach and withdrawal behaviors (e.g., Davidson, 1992, 1995; Harmon-Jones, 2003, 2004). This asymmetry is very robust and corresponds to both trait differences in approach and withdrawal tendencies (e.g., Harmon-Jones and Allen, 1997; Sutton and Davidson, 1997) and state (situational) fluctuations in approach and avoidance motivational states (e.g., Harmon-Jones and Sigelman, 2001). Although some models posit that all positively-valenced stimuli elicit approach and all negatively-valenced stimuli elicit avoidance (e.g., Sutton and Davidson, 1997), other evidence indicates that negative experiences (e.g., anger) are associated with approach behavior and increased left-frontal cortical activation (see Harmon-Jones, 2003), suggesting that frontal cortical asymmetry reflects motivational direction (i.e., approach vs. avoidance) rather than emotional valence (i.e., positivity vs. negativity). Thus, even though behavioral implicit measures such as the IAT consistently show that both heavy and light drinkers associate alcohol with negative valence, it could be that heavy drinkers experience more left-frontal cortical activation in the presence of alcohol-related cues than do more moderate drinkers, reflecting their increased motivation to drink. To date, however, research on addiction has largely ignored this measure (but see Ehlers et al., 2001).

When EEG recordings are time-locked to the repeated presentation of stimuli, event-related brain potentials (ERPs) are generated (see Fabiani et al., 2000). Whereas background EEG provides information about tonic motivational states, ERPs reflect phasic changes in brain activity corresponding to cognitive processing of particular stimuli. The P300 component of the ERP is particularly relevant for assessing neural responses that could reflect substance-related motivational processes. P300 amplitude is known to increase along with the motivational relevance or emotional salience of a stimulus (Ito et al., 1998; Schupp et al., 2000). A few studies have shown that alcohol cues elicit increased P300 amplitude, and that this P300 response correlates with cue-induced craving, both in heavy social drinkers (Herrmann et al., 2001) and in alcoholics (Herrmann et al., 2000; Namkoong et al., 2004). While not conclusive, these data suggest that the P300 may reflect a relevant motivational state in relation to alcohol use and misuse.

Recently, there have been rapid developments in a number of non-invasive brain imaging methods, including functional Magnetic Resonance Imaging (fMRI), and in application of these methods to the study of addiction (e.g., Franken et al., 2006). The work of Tapert and colleagues has been important in using this methodology to study adolescent alcoholics (e.g. Tapert et al., 2003, 2004). Interestingly, Tapert and colleagues used an indirect method to assess brain responses to alcohol-related vs. neutral cues: rather than letting participants rate their subjective craving to alcohol-related stimuli in the scanner, participants had to indicate the number of words on the screen (the same word was printed one, two, three or four times). These words were alcohol-related or neutral (using blocked presentation). The differences in brain responses between these blocks were compared between the alcohol dependent and control subjects, resulting in a number of differentially activated brain areas (Tapert et al., 2004). Increased subjective craving after the task was uniquely related to increased Brain Oxygen Level Dependent (BOLD) responses in the subcallosal cortex, a limbic area including the Nucleus Accumbens, suggesting that the automatic activation of limbic systems involved in appetitive motivation concerns an important element in alcohol and drug use motivation. According to some theorists, this activation can (but does not necessarily) reach conscious awareness to influence behavior (Berridge, 2001; Robinson and Berridge, 2003; Winkielman et al., 2005, see below).

Finally, it should be noted that approach and avoidance reactions can be viewed as a bipolar continuum, but that it is also possible that approach and avoidance reactions are based upon separate processes (e.g. Cacioppo and Berntson, 1994; Gray, 1990; Frank and Claus, 2006). This notion has been reiterated in relation to the development of addictive behaviors (e.g., Baker et al., 2004; Breiner et al., 1999; Wiers et al., 2006a). In support of this view, it has been demonstrated that the independently assessed (subjective) approach and avoidance tendencies uniquely predicted substance-related behaviors, both in young adults (Stritzke et al., 2004) and in adolescents (Curtin et al., 2005). This could provide a possible explanation for the relatively unreliable findings for many psychophysiological measures in cue-reactivity research (cf. Glautier, 1999): if both an appetitive and an aversive reaction can be triggered with an opposite effect on a psychophysiological measure, much variance can be expected due to individual differences and associative qualities of specific stimuli (e.g. aspects of a stimulus that highlight positive vs. negative aspects of drugs, cf. Sherman et al., 2003). Clearly more research on this interesting subject is needed, and maybe new techniques (e.g. ERP, fMRI) will better be able to distinguish between appetitive and aversive processes in human cue-reactivity.

2.2.4. Relationships between different implicit measures of appetitive motivation

Thus far, many different measures of appetitive motivation have been presented. An important next question is to what

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extent these measures tap into a single appetitive motivational process or into different processes. As outlined earlier, many current dual process models propose that implicit and explicit processes can be distinguished, with the key difference being the representational format (associations vs. propositions, Gawronski and Bodenhausen, 2006; Strack and Deutsch, 2004). This does not imply that implicit and explicit measures of appetitive motivation are necessarily independent (in fact, the typical finding is a low positive correlation), but it does imply that they can differ (e.g. one can have an association, but not support the corresponding explicit proposition, see above) and that the two can respond differently to interventions (cf. Wiers et al., 2005, 2006b).

Less is known about the relationship between measures of attentional bias and measures of implicit memory associations. Theoretically, there are reasons to hypothesize a relationship between attentional processes and memory. First, some general theories in cognitive science consider the two to be closely related or "two sides of the same coin". For example, Logan (2002) provided a general theory of cognition that integrates memory and attention under the same general cognitive system. In this theory, attention and memory are seen as different manifestations of the same process. To Cowan (1988), attention effects such as selective attention, and attentional bias, cannot occur without some system for coding perceptions. His theory postulates that a fast-acting memory process applies these codes to direct attention. For example, it is possible that automatic semantic or associative priming, known to operate very rapidly, may activate drug-related associations that steer further processing (Stacy et al., 2004). Second, in general theories of mechanisms underlying different psychopathologies "current concerns" are an important concept (Cox et al., 2006a,b; Harvey et al., 2004; Cox and Klinger, 2004). This refers to a time-binding process that begins when the individual becomes committed to pursuing a goal and continues until the goal is attained or the person gives up the pursuit. "Time-binding" indicates that the current concern is an enduring neural process which goes on outside conscious awareness, and which "most likely periodically injects goal-related ideation into the person's stream of consciousness" (Cox et al., 2006a,b, p. 254–255). Current concerns influence contents of dreams and influence the allocation of attention (attentional bias is often interpreted as the expression of a current concern, Cox et al., 2002, 2006a,b; Harvey et al., 2004). For a current concern to exert influence on cognitive processes, it needs to be represented in memory. Hence, there are clear theoretical reasons to hypothesize different measures of appetitive motivation should be positively correlated, including measures of attentional bias for a drug and measures of implicit associations. Further, within each category one also expects positive correlations.

What is the evidence? First, there is a remarkable paucity of research investigating the relationships between different measures of implicit appetitive motivation. Second, in other areas of psychology, it has been found that different implicit measures hardly correlate (e.g. Bosson et al., 2000), which appears to be at least partly due to measurement error (Cunningham et al., 2001). Some research combined different measures of implicit appetitive motivation in the field of alcohol and drug use. Field et al. (2005a) found a positive correlation between attentional bias (assessed with a visual probe task) and explicit evaluation of alcohol stimuli and between the explicit evaluation and automatic approach associations (assessed with the manikin task), but no direct correlation between attentional bias and automatic approach associations. All measures were positively associated with self-reported craving. This study may be interpreted as partial support for the general idea that these different measures could assess (different facets of) a general underlying construct: appetitive motivation to use alcohol. A recent study by Van den Wildenberg et al. (2006) assessed attentional bias (alcohol Stroop), and both approach and arousal associations with the IAT in heavy drinking students. Implicit approach associations assessed with the IAT (as in Palfai and Ostafin, 2003) correlated significantly with Stroop-interference scores, the correlation with arousal associations (assessed with a unipolar IAT, as introduced above, cf. Houben and Wiers, 2006a) was in the expected direction, but not significant ($r=0.23$, $p=0.06$ one-tailed). Alcohol-approach associations were related to increased craving during the ascending limb of the Blood Alcohol Curve (BAC) and alcohol-arousal associations were correlated with alcohol-related problems. These data are generally in line with the idea that different implicit measures of appetitive motivation to drink assess different aspects of relatively spontaneous appetitive processes. A developmental study in adolescents using a selection of these measures in relation to the development of alcohol use and problems would be most interesting.

2.2.5. The role of conscious awareness in measures of appetitive motivation

Until now there have been few investigations of reactions to subliminally presented alcohol- or drug-related stimuli (outside conscious awareness), as have been reported in anxiety research (e.g., Mogg and Bradley, 1998; Ohman, 2002). Franken et al. (2000) found no effects of subliminally presented heroin words in a drug-Stroop test, while a reliable drug-word interference effect was found for words which were presented long enough to reach conscious awareness. A recent review concluded that appetitive reactions are fundamentally different from anxious reactions, because addictive behaviors are associated with biases in later attentional processes (attentional disengagement), while for anxiety there is evidence of associations with very early attentional processes (initial orienting) which may occur outside awareness (Field et al., 2006). There is evidence that attentional disengagement is related to subjective craving (Field et al., 2006) and conversely that the level of craving or deprivation affects late attentional processes, in the absence of effects on early attentional processes, both in normal appetitive processes (hunger, Mogg et al., 1998), and in different craving states in addictive behaviors like smoking (e.g., Field et al., 2004b) and alcohol use (Field et al., 2005a). The idea that some level of subjective awareness is a necessary component for cognitive and attentional biases to occur in alcohol and drug use is also supported by a recent review on nicotine conditioning in humans, which concluded that explicit awareness of contingencies is a necessary condition for the occurrence of a conditioned appetitive response (Hogarth and Duka, in press). Hence, the general picture that emerges from this literature is that attention and cognitive motivational mechanisms in alcohol and drug misuse are relatively slow in comparison to the fast operating mechanisms that play a role in anxiety disorders. This may be related to a stronger evolutionary pressure for detection of a threat as compared to an appetitive stimulus (cf., Ohman, 2002).

However, some recent evidence undermines this clearcut conclusion. On the one hand, some studies have found evidence for preconscious processing of appetitive stimuli. Ingjaldsson et al. (2003) found that alcohol-related stimuli presented outside conscious awareness resulted in reliable changes in alcoholics' heart rates, but only in those alcoholics who scored high on craving for alcohol. Further, regarding normal appetitive states, Winkielman et al. (2005) demonstrated in two studies that drinking motivation was influenced by the presentation of subliminal emotional faces (happy faces lead to stronger drinking motivation than neutral faces, which lead to stronger drinking motivation than angry faces), but only in those participants who were thirsty. Interestingly, in these individuals the change in drinking motivation occurred in the absence of a change in subjective mood. Hence, at least some studies have demonstrated preconscious effects for appetitive stimuli in participants for whom appetitive motivation was strong (thirst, craving). On the other hand, some recent fMRI studies have indicated that also for the detection of fear eliciting stimuli a minimal level of attention and awareness are necessary (Pessoa et al., 2005b, 2006), after controlling for individual differences in the ability to detect briefly presented stimuli (Pessoa et al., 2005a).

In conclusion, the weight of the evidence indicates that attentional and cognitive processes which are important in addictive behaviors are "later" or slower than those in fear detection and anxiety, but at least some recent studies suggest that this difference should not be seen as absolute. In addition, there are a number of issues in studies on the role of subjective awareness in the processing of emotional stimuli, including subjective vs. objective criteria (e.g. Merikle et al., 2001) and individual differences in these abilities (see Pessoa et al., 2005a). Again, it should be emphasized that the recent body of work on implicit cognitive motivational processes in addictive behaviors reviewed above, involves tests that do not exclude some level of awareness. Rather these tests attempt to assess a number of relatively spontaneous and automatic processes pertaining to addictive behaviors, as contrasted with the more deliberate processes that also are involved. The exact role of subjective awareness in these tests awaits further research (De Houwer, 2006), as does its role in addictive behaviors.

3. Control over appetitive motivation

Once an individual has initiated drinking (and/or the use of other drugs) and as a result the appetitive motivation to use alcohol has increased (especially after exposure to drug cues), it becomes important whether he or she gives in to this impulse or controls it. In line with other dual process models in psychology (e.g. Fazio, 1990; Fazio and Olson, 2003; Metcalfe and Mischel, 1999; Payne, 2005), we propose that there are two crucial factors which determine whether the impulse to drink or use drugs is followed or controlled: *ability* to inhibit (or to redirect attention or goals) and *motivation* to do so (see Fig. 1, and for many other examples of dual process models in addiction, see Wiers and Stacy, 2006).

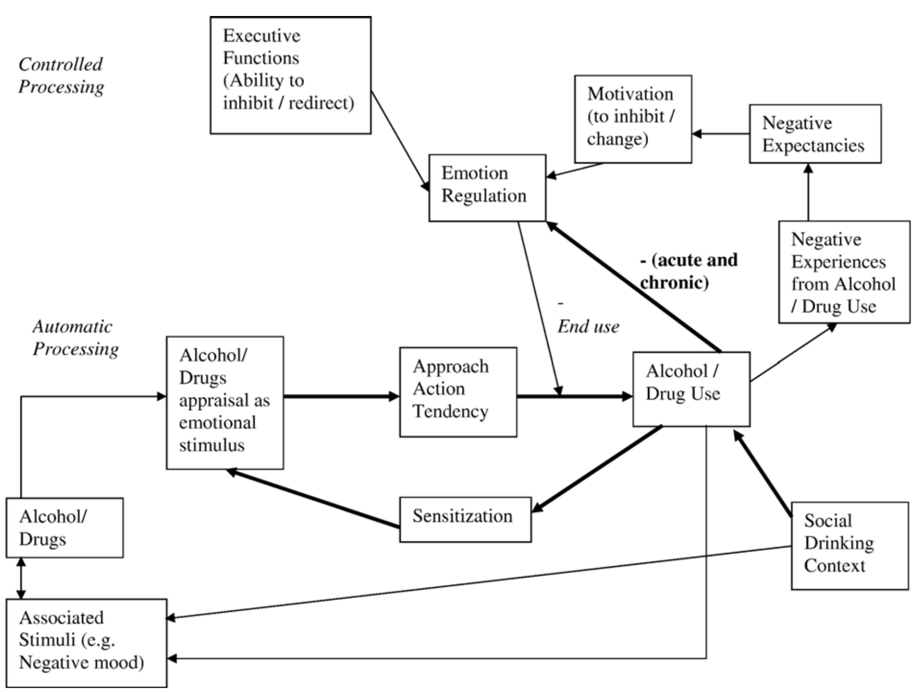

Fig. 1.

3.1. Ability to control appetitive motivation

The ability of controlled processes to moderate the impact of spontaneous affective reactions on behavior is an important component of emotion regulation (e.g. Gross, 1998), which is not yet fully developed during adolescence (Forbes and Dahl, 2005). This ability is also a central element of Executive Cognitive Functions (ECFs). Recent research suggests that attainment of ECF begins as early as age 1 and continues well into the second (e.g., Anderson et al., 2001; Luciana et al., 2005; Luciana and Nelson, 1998; Luna and Sweeney, 2004) or even the third (Luna et al., 2004) decade of life. The changes in frontal brain structure that occur in adolescence (e.g., Rubia, et al., 2000) coincide with increased executive control over behavior (e.g., Benes, 2001; Luna and Sweeney, 2004; Luna et al., 2001; Segalowitz and Davies, 2004). Contemporary models have identified three core executive abilities thought to underlie self-regulation: inhibitory control, working memory updating, and mental set shifting (see Miyake et al., 2000). Of these, inhibitory control and working memory updating are believed develop most strongly in adolescents (see Luna et al., 2004; Segalowitz and Davies, 2004) and both have been associated with the development and maintenance of addictive behaviors (see Bartholow et al., 2003a; Fillmore and Vogel-Sprott, 2006).

Recently, a distinction between “cool” and “hot” ECFs has been proposed (Metcalfe and Mischel, 1999). “Cool” ECFs are assessed with relatively abstract decontextualized tasks such as the Stop task (Logan et al, 1984) and are associated with the dorsolateral prefrontal cortex. “Hot” ECFs are assessed with tasks that involve affective processes, assessed with tasks such as the Iowa Gambling Task (Bechara et al., 1997) and are associated with activity in the orbital and medial prefrontal cortex (Castellanos et al., 2006). Both types of inhibitory processes may be relevant for the development of addictive behaviors (see also Bechara et al., 2006).

Different psychophysiological measures have been proposed to reflect the development of ECFs, such as heart-rate variability (e.g., Hansen et al., 2003; Thayer and Lane, 2000) and ERPs. A number of ERP components have been specifically associated with particular executive functions. Broadly, the amplitude of the P300 component is believed to index working memory updating (Donchin and Coles, 1988), and the N2 and negative slow wave (NSW) components are believed to reflect conflict and control processes associated with inhibition of dominant responses (Curtin and Fairchild, 2003; West and Alain, 2000). Additional conflict and control processes are reflected in the amplitude of the error-related negativity (ERN) and error positivity (Pe), a set of components that occur immediately after an incorrect response in many tasks (see Holroyd and Coles, 2002; Vidal et al., 2000). Segalowitz and Davies (2004) have described a useful strategy for using ERPs to chart frontal lobe development. The approach involves obtaining ERP measures of regional brain activation, correlating these measures with behavioral indicators of the development of ECF, and charting these relations through ontogenesis.

Recent fMRI studies have provided additional information regarding the neural substrate underlying the regulation of emotional responses, including appetitive responses (e.g. Ochsner and Gross, 2005). These regions are known to be important for a number of executive abilities and have been hypothesized as important sites of ethanol action in the brain that might underlie alcohol-induced deficits in ECF (see London et al., 2000; cf. Bartholow et al., 2003a). Several studies have indicated that right ventral lateral prefrontal cortex activation is related to control over fast evaluative responses that are likely to be similar to impulsive appetitive associations. There is also evidence that another type of cognitive regulation (reappraisal strategies, which involves reinterpretation of the meaning of a stimulus) is associated with other brain systems, including lateral and medial regions of the prefrontal cortex (Ochsner and Gross, 2005). Different strategies that can be used to control automatic appetitive responses are outlined below.

In conclusion, many studies have documented that ECFs are still developing in late adolescence and early adulthood, which may make these processes especially vulnerable for alcohol and drug use at this age (Dahl, 2004; Dahl and Spear, 2004). A number of neuropsychological tests have been developed to assess different aspects of ECFs, and various psychophysiological measures can reveal the neural underpinning of these functions. Important for present purposes are acute and long-term effects of alcohol and drugs on ECFs and individual differences in ECFs, which may be related to an individual’s risk for developing problems with alcohol and other drugs. Both are discussed below.

3.2. Motivation to control appetitive motivation

As indicated in the model, it is one thing to be able to regulate appetitive behavioral tendencies, it is another thing to also be willing to do so. We know of little systematic research on this topic, but it is our impression from our own studies with high-risk youth that the large majority of potential participants do not see themselves as having a problem, or even as being at risk for developing a problem, even though their scores on standardized questionnaires indicate otherwise. For this reason, studies in which we advertised with “an intervention” in youth have been largely unsuccessful in recruitment (e.g., Thush et al. in Stewart et al., 2005, see also Thush et al., this issue). We have been more successful in recruiting heavy drinking youth by advertising “fun experiments about alcohol”, not mentioning any intervention, even when in fact participants took part in an intervention study (e.g., Wiers et al., 2005). In this study, we recruited 96 heavy drinkers in this way. Of these participants, 75% scored above clinical norms for an alcohol problem on the AUDIT (a score of 10 or higher) and average alcohol consumption was 30 drinks per week. We also assessed a family history interview, in which participants indicated for each first or second-degree relative whether they thought this person had an alcohol problem. In this context we also asked them to indicate this for themselves. The striking finding was that only one participant self-reported having an alcohol problem. Hence, the large majority of participants had an alcohol problem as indicated by their scores on standardized instruments but did not indicate so, when asked directly. To further illustrate the seriousness of the alcohol problems in this sample, one of our four drop-outs was surely alcohol-related: the participant had cycled into a wall at night and was in the hospital during the second assessment.

This case-story also illustrates one of the few occasions in which adolescents may realize that their alcohol or drug use is problematic: directly following an alcohol-related accident. For this reason, recruitment at hospital first aid settings (especially at night during the weekend) has been shown to be a good strategy in adolescents and a good moment to use a motivational interview (e.g., Monti et al., 1999). There is some evidence for an important role of negative expectancies (of continued heavy use) in motivation to change behavior (Jones and McMahon, 1998; Metrik et al., 2004, see below). In the absence of salient alcohol-related problems (and the acknowledgement that these problems are due to alcohol or drug use), adolescents are unlikely to inhibit appetitive motivation to drink, especially in (sub-)cultures where heavy drinking is the norm. Indeed, low motivation to change behavior has been found in heavy smoking adolescents (e.g. Engels et al., 1998) and in heavy drinking adolescents (Sher and Epler, 2004). It should be noted that the impact of motivation to change is not only important in adolescent alcohol and drug use, but also in adults both in treatment and in spontaneous recovery (e.g. Miller, 1998).

4. Acute and chronic effects of alcohol and drugs

When consumption of alcohol and other drugs is seen as the result of a dynamic interplay between relatively spontaneous appetitive motivational processes on the one hand, and controlled regulatory processes on the other hand, it becomes important to consider what happens to both processes as a result of alcohol and drug use, while distinguishing acute and chronic effects.

Regarding acute effects, there is evidence that a small dose of alcohol primes appetitive motivational processes (e.g. Glautier et al., 1992; Mucha et al., 2006). For example, a priming dosage of alcohol increases the attractiveness of alcohol cues (Jones and Schulze, 2000; Duka and Townshend, 2004) and of smoking cues (Palfai et al., 2000; Field et al., 2005b). Meanwhile there is also increasing evidence that alcohol and many other drugs selectively impair controlled executive processes, particularly inhibitory control (see e.g., Fillmore and Vogel-Sprott, 1999, 2000; Fillmore et al., 1999, see for a recent review Fillmore and Vogel-Sprott, 2006). The numerous behavioral findings characterizing the detrimental effects of alcohol consumption on controlled processes have a counterpart in psychophysiological indices of cognitive control. In general terms, moderate doses of alcohol (typically ranging from .5 to 1.0 g/kg) attenuate the amplitude and increase the latency of ERP components associated with controlled cognitive processes. For example, Curtin and Fairchild (2003) found that alcohol impaired Stroop-task performance and attenuated the amplitude of two ERP components, the N450 and the negative slow wave (NSW), which are associated with conflict and detection and engagement of regulative cognitive control processes, respectively. This finding suggests that alcohol-induced behavioral decrements in this task resulted from disruption of conflict detection and control. Bartholow et al. (2006) similarly found that alcohol increased inhibition failures in a stop-signal task (Logan, 1994) and that these behavioral effects were correlated with decreased amplitude of the NSW component of the ERP. In another study, Bartholow et al. (2003b) found that, relative to placebo, alcohol reduced the amplitude and increased the latency of the P300 component on high-conflict trials in a response conflict task (flanker task), suggesting that alcohol impaired conflict resolution processes (see also Ridderinkhof et al., 2002). The extent to which alcohol affects the magnitude and timing of ERP components in adolescents is an important question for further research. This brief summary on acute effects suggests that consuming a moderate dose of alcohol can lead to continued drinking, for two reasons: an initial dose of alcohol tends to increase appetitive motivation to drink, and moderate intake produces a decrease in the ability to regulate behavior and control impulses. Together, these processes can prolong drinking episodes, particularly in adolescents with not yet fully developed regulatory processes.

In addition to these acute effects, there is also evidence indicating that the long-term effects of heavy alcohol and drug use are similar: appetitive motivational processes sensitize as a result of use (Robinson and Berridge, 2003) and controlled regulatory processes are negatively affected, especially in case of alcohol or drug abuse during adolescence (Dahl and Spear, 2004). Animal studies have revealed that alcohol exposure (especially at intoxicating dosages) impairs cognitive abilities more in adolescents than in adults (e.g., Monti et al., 2005; White et al., 2000; White and Swartzwelder, 2004) and that this impairment is long-lasting. Studies involving human adolescents who chronically abuse alcohol have revealed deficits in executive abilities (e.g., Brown et al., 2000) and abnormal patterns of brain activity during the performance of executive cognitive tasks (Tapert et al., 2004). In contrast, some evidence suggests that alcohol use disorder that begins during young adulthood has limited long-term effects on cognitive abilities (Wood et al., 2002). Animal research suggests that chronic alcohol involvement in adolescence can have negative consequences for the maturation of a number of brain regions, including structures with extensive projections to prefrontal cortical areas that support ECF (e.g., DeBellis et al., 2000; White and Swartzwelder, 2004). Taken together, these findings suggest that adolescent alcohol involvement can have lasting negative consequences for the development of ECF, which has implications for regulating the ability to inhibit appetitive motivation. In addition, this impairment may have a negative effect on social-cognitive functioning. For example, research shows that executive working memory updating is critical for normal social-cognitive functioning (Macrae et al., 1999). Executive control processes can override the automatic operation of preexisting cognitive schemas when perceivers encounter novel situations (e.g., Baddeley et al., 2001; Baddeley and Logie, 1999; Norman and Shallice, 1986). Unexpected behaviors trigger neural working memory updating mechanisms (Bartholow et al., 2003), resulting in better recall of expectancy-violating compared with expectancy consistent information (for reviews see Stangor and McMillan, 1992;

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Ybarra, 2002). In conclusion, both acute and chronic effects of alcohol (and many other drugs) result in a strengthening of associative appetitive motivational processes and a weakening of controlled regulatory processes. Together this shifts the balance between these processes towards increased use and problems.

5. Individual risk factors

From the present perspective, individual risk factors can be related to all aspects of the model. First, there is evidence that individual differences in sensitivity to rewarding effects of a drug are related to the risk to develop an addiction (e.g. Kambouropoulos and Staiger, 2001). It is well established that children of alcoholics (COAs) are at enhanced risk for the development of addiction (see Sher, 1991). There is also evidence that they demonstrate stronger psychomotor stimulant activation and subjective feelings of arousal after rapid consumption of alcohol (Conrod et al., 2001; Gianoulakis et al., 1996; Peterson et al., 1996). This is likely to be reflected in stronger expectancies of positive arousal after the onset of drinking, as Wiers and colleagues found in adolescent COAs (Wiers et al., 1998b) and in alcoholics in treatment (Wiers et al., 2000).

To date, very few studies have examined the effects of familial risk for alcoholism using implicit measures. In a study introduced above, Wiers et al. (2005), assessed both implicit and explicit alcohol-related cognitions in a sample of 92 problem drinkers, including 16 COAs and 75 Non-COAs (and one adopted participant who was left out of present analyses, which were left out of the original report due to space limitations). In line with the idea that implicit arousal associations may reflect a partly genetically-determined sensitized psychomotor stimulant reactions to alcohol, COAs showed stronger alcohol-arousal associations at pretest than controls ($p=0.04$, one-tailed). The strength of this association was reduced somewhat after controlling for present alcohol use ($p=0.051$, one-tailed). In addition, COAs scored higher on explicit expectancies of tension reduction, also after controlling for current alcohol use ($p<0.05$), as has been reported before (e.g. Mann et al., 1987). Interestingly, implicit arousal associations and explicit expectancies of tension reduction were positively correlated, a counterintuitive finding which was recently replicated (Van den Wildenberg et al., 2006). On both variables COAs scored higher than non-COAs. Apparently, individuals who show stronger alcohol-arousal associations also report to relax more from drinking alcohol. There is some evidence that COAs more strongly experience tension-reducing effects of alcohol (Sher, 1987) and it is an interesting question to what extent these effects are related to a stronger appetitive response to alcohol. To our knowledge there are only two studies comparing cue-reactivity of COAs with controls (both reported in Walitzer and Sher, 1990), which showed only partial support for the hypothesis that COAs would show stronger cue-reactivity than controls. In summary, there is preliminary evidence that individual differences in rewarding effects of alcohol and drugs are related to risk for addiction, but more research is needed in this area.

Second, there is evidence that COAs not only more strongly experience the positive arousing effects directly after drinking alcohol than controls but also less strongly experience the negative sedating effects of alcohol that occur later during a drinking episode (Newlin and Thompson, 1990). Schuckit and Smith (1996) showed that a high tolerance to the negative intoxicating effects of alcohol (called a “low level of response”) is a strong predictor for developing later alcohol problems. One would expect that this is reflected in relatively weak negative associations and expectancies of alcohol (cf. Wiers et al., 1998b). Unfortunately, most studies directly relating level of response to alcohol expectancies included a measure of positive expectancies only (Schuckit, 1998; Schuckit et al., 2005). The association between low level of response and later alcohol problems was found to be partially mediated by positive expectancies.

Third, individuals differ in their ECFs and in their ability to regulate their impulses. Behavioral disinhibition is one of the most robust predictors of later addictive behaviors (Sher, 1991; Sher et al., 1991, 1999). It has also been proposed that COAs have specific impairments in the development of their ECFs, which could mediate their risk for later addiction (Pihl et al., 1990; Pihl and Bruce, 1995). One caveat is that impairments in ECFs have also been associated with other psychopathology including ADHD and Conduct Disorder (e.g. Barkley, 1997; Oosterlaan et al., 1998) and COAs often demonstrate signs of ADHD and conduct problems (a trait named behavioral undercontrol, Sher, 1991; Sher et al., 1991). Wiers et al. (1998a) examined ECFs in sons of multigenerational alcoholics and compared their scores with boys with ADHD and no alcoholism in the family and with normal controls (no family history of alcoholism and no ADHD). Deficits in ECFs were found for the boys with ADHD but the effects among COAs were limited to those boys who scored high on symptoms of ADHD and CD. Similar findings were recently reported by Habeych et al. (2006). In line with the previously mentioned differentiation between “hot” and “cold” ECFs (Castellanos et al., 2006), it seems likely that COAs are most strongly impaired in “hot” ECFs, but we know of no research directly testing this hypothesis yet.

Psychophysiological measures can be used to disentangle processes associated with familial risk from other psychopathology and from use of alcohol. Of particular relevance here is evidence pointing to reduced P300 amplitude as an endophenotype for the development of alcoholism (e.g., Carlson et al., 2004; Polich et al., 1994; Porjesz et al., 2005). Background of this hypothesis are numerous studies showing that individuals at risk for developing alcoholism show a small P300 amplitude compared with controls (Polich et al., 1994; Porjesz and Begleiter, 1998; Van der Stelt, 1999). Recent work has indicated that small P300 amplitude predicts unique variance in onset of alcohol use disorders beyond that accounted for by family history of alcoholism and other psychopathology, at least in males (e.g., Iacono et al., 2002; but see Habeych et al., 2006). A small P300 also has been related to behavioral undercontrol (Ratsma et al., 2001), a strong predictor of alcohol abuse (Sher et al., 1991, 1999), but again the evidence is somewhat equivocal (cf. Habeych et al., 2006). One small fMRI study testing young adolescent COAs vs. controls (Schweinsburg et al., 2004), found less strong inhibitory frontal responses in COAs.

An interesting and as yet mostly unexplored question concerns the relationships between these risk factors. For example, behavioral undercontrol is related to positive expectancies from drinking (e.g., Henderson et al., 1994; Sher et al., 1991), and these expectancies are related to frontal brain functioning (e.g. Deckel et al., 1995). In addition, Bartholow and colleagues (unpublished data) found that social drinkers with low alcohol sensitivity (i.e., individuals who report needing more alcohol in order to feel subjective effects) show enhanced P300 responses to alcohol cues relative to neutral beverage cues, which was not found in social drinkers with high alcohol sensitivity. This finding is noteworthy given that low alcohol sensitivity has been associated with reduced P300 amplitude in cognitive tasks (Bartholow et al., 2003).

In summary, there is preliminary evidence linking individual differences in risk for alcoholism to different aspects of the model: higher sensitivity to reward in general and to rewarding and stimulating effects of alcohol in particular, less ability to inhibit (appetitive) response tendencies and probably also less motivation to do so, because of a low sensitivity to the punishing effects of alcohol. However, the data are scattered and not always consistent. Clearly an integrated research effort examining different aspects of the model would be helpful. Moreover, alcoholism and drug abuse are not isolated disorders. Rather, they are part of a spectrum of disorders characterized by externalizing traits (behavioral undercontrol, symptoms of ADHD and conduct problems), disinhibited behaviors, and a heightened sensitivity to the incentive salience of arousing experiences, including drug and alcohol use. Recent research points to the conclusion that the genetic risk associated with family history of alcohol and drug problems represents a generalized vulnerability to externalizing psychopathology, and alcohol and drug abuse in offspring represent one of a number of related expressions of this vulnerability (see Hicks et al., 2004). It will be important in future tests of our model to determine the extent to which effects of family history are mediated by appetitive motivation for alcohol and deficits in ECF at baseline, prior to any substance involvement.

6. A caveat: it's the environment, dummy!

In all of the above, the emphasis has exclusively been on intra-individual factors that may predict why one adolescent develops an alcohol or drug problem, while the other does not. An important caveat is that researchers often ignore the fact that most alcohol and drug use in adolescence takes place in the social environment (e.g., Knibbe et al., 1993), and that the social environment itself is already an important predictor of alcohol use and misuse. A (social) context can trigger appetitive motivation (for many examples both with implicit and explicit measures, see Krank et al., 2005).

A social environment can influence risk-status. For example, college students who join the fraternity system are at enhanced risk of developing alcohol problems (Bartholow et al., 2003c; Larimer et al., 2004). Of course these effects cannot only be attributed to the environment: selection processes also play a role (Bauman and Ennett, 1996). Once young people get involved in a romantic relationship, they change their drinking pattern (especially men drink less as a result of spending increasingly more time in 'dry' settings, Engels and Knibbe, 2000).

At a more fine-grained level of analysis, longitudinal studies have shown that adolescents' alcohol use is affected by the consumption patterns of best friends and peer group members (e.g., Bauman and Ennett, 1996; Bot et al., 2005b; Engels et al., 1999; Urberg et al., 2003), which appears to be driven by implicit and explicit drinking norms in peer groups (Bot et al., 2005b). Moreover, experimental observational studies have shown that the drinking pace of a confederate strongly affects individual drinking rates and consumption levels (see Quigley and Collins, 1999, for a review). Further, there are important sex differences in the effects of social context on drinking. Using multilevel analyses on observational data from mixed-sex groups, Engels et al. (2005a,b) demonstrated that, in contrast to men, women are not strongly affected by average drinking levels in a group (cf., Suls and Green, 2003). It has been proposed that women moderate use in mixed-sex contexts in order to maintain self-control in the presence of men (Suls and Green, 2003), but there is as yet little empirical evidence for this assertion.

A limitation of most experimental observational studies is the use of a taste-test approach in a laboratory setting, of which the ecological validity has been questioned (Bot et al., 2005a). A taste test does not reflect a natural social drinking situation and does not assess ad lib drinking behavior: people are obliged to consume at least some alcohol which makes it more difficult to generalize these findings to a situation in which one is not obliged to consume. A second limitation of these studies is the fact that they typically model imitation processes in dyads of strangers as compared to friendships, which limits the potential to generalize the findings to real-life drinking situations. Surprisingly, direct systematic observations of imitation and drinking in peer groups in naturalistic settings have been made in only one study we know (Bot et al., 2005a). This study showed strong effects of peer norms on drinking, even after controlling for habitual drinking. Systematic observation studies would also be particularly interesting to combine with assessment of implicit motivation to drink, because studies in other domains have demonstrated that implicit measures better predict spontaneous behaviors than explicit measures (e.g. Spalding and Harding, 1999; Huijding and De Jong, 2006). Thus, there is a need for controlled research linking individual differences in intrapersonal processes related to drinking (e.g., ECF, approach tendencies) with interpersonal processes that unfold during natural social interactions, particularly since many of the problems associated with alcohol consumption (e.g., aggression, sexual risk-taking) are interpersonal in nature and related to ECFs.

7. Implications for interventions

From the present perspective, there are different strategies one can employ in interventions tailored to adolescents. The most important thing appears to be to try to minimize alcohol and drug use during adolescence, given the effects described above (sensitization of stimulant response and weakening of self-regulating abilities). Of course, the million dollar question is how to effectively achieve this. Given the fact that most alcohol- and drug use takes place in a social context, approaches which only target the individual may be insufficient. School-based primary prevention has been shown to have limited effects (Foxcroft et al., 1997, 2003). For instance, findings of an experimental study showed that the most popular prevention program in the Netherlands, 'Healthy School and Drugs project', did not result in short term or long term effects on alcohol intake among young people and there was even evidence for paradoxical effects on marijuana use (Cuijpers, 2002; Cuijpers et al., 2002). For a more positive appraisal of American primary intervention programs, see Botvin et al., 2001; Botvin and Griffin, 2004). In line with the present model, there is some evidence that primary prevention programs that affect adolescents' social motivation to use substances, can be effective (Donaldson et al., 1994; MacKinnon et al., 1991; Orlando et al., 2005).

Regarding more targeted prevention, a promising approach is Motivational Interviewing (MI, Dimeff et al., 1999; Miller and Rollnick, 2002), which has been successfully applied in college students (Marlatt et al., 1998), with effects up to four years after a brief intervention (Baer et al., 2001). These interventions typically involve a brief, one-on-one interview with a person who is currently using a drug such as alcohol but has not yet reached the level of dependence on that drug as defined by DSM-IV criteria (Dimeff et al., 1999). The interviews may be one or two sessions that last anywhere from 30 min to 2 h each. The trained interviewer maintains an empathic attitude toward the interviewee and discusses concerns that the interviewee might have about substance use. The emphasis is for the interviewee to take responsibility for his or her behavior related to substance use. Motivational interviewing is based in part on self-regulation theory (Miller and Rollnick, 2002). Interventions based upon adaptations of motivational interviewing are now being applied to substance abuse interventions among younger adolescents (for reviews, see Grenard et al., in press; Tait and Hulse, 2003). There have been mixed results for the few clinical trials that have been conducted among adolescents, but studies have successfully applied adaptations of motivational interviewing to alcohol use among adolescents in an outpatient clinic (Aubrey, 1998), an emergency department (Tait and Hulse, 2005), and in a school setting (McCambridge and Strang, 2004). We suspect that MI will not directly influence appetitive motivation, but rather that it may help to moderate the effect of appetitive motivation on alcohol or drug use (see Fig. 1, cf. Payne, 2005). A related approach (sometimes incorporated in MI, e.g. Dimeff et al., 1999) is to provide individuals with feedback about drinking of others (perceived social context). The processes targeted by this approach are "false consensus" (i.e., heavier drinkers tend to believe that others are likely to be heavy drinkers, Bauman and Geher, 2002; Ross et al., 1977; Suls et al., 1988) and "pluralistic ignorance" (i.e., that there is a common but false belief about the extent of heavy drinking in the population; Isenberg, 1980; O'Gorman, 1986). These processes work against self-recognition of excessive drinking or a drinking problem (Sher and Epler, 2004), which we believe is an important prerequisite for attempts to regulate addictive behaviors. Therefore, it may be useful to target adolescent who are already drinking and using drugs with interventions that confront these common cognitive biases, although it should be mentioned that this does not always result in significant decrease of drinking (cf. Thush et al., this issue).

Another approach is to try to reduce the appetitive motivational responses to alcohol and drug cues. This can be done with pharmacotherapy (e.g. Naltrexone), which is beginning to be applied in adolescents (Deas et al., 2005; Lifrak et al., 1997; Niederhofer et al., 2003). An alternative approach is cue exposure which aims to extinguish cue-reactivity through repeated exposure to alcohol or drugs without subsequent consumption (Drummond et al., 1995). However, we do not know of studies testing it in adolescents and studies in adults have not been very successful from a clinical perspective (Conklin and Tiffany, 2002; Havermans and Jansen, 2003). As to cognitive processes involved in appetitive motivation, most studies until now have tried to change explicit positive expectancies. One interesting method is the expectancy challenge method, developed by Darkes and Goldman (1993, 1998). This procedure has been found to decrease positive expectancies in young adult men (Darkes and Goldman, 1993, 1998) and also in younger samples (Thush et al., this issue; Wiers et al., 2005), including a heavy drinking adolescent sample (Van de Luitgaarden et al., 2006). However, effects on alcohol consumption were either absent (Thush et al., this issue), limited (Van de Luitgaarden et al., 2006) or short-lived (Wiers et al., 2005). Moreover, Wiers et al. (2005) found that while the expectancy challenge changed explicit alcohol expectancies, it hardly affected implicit associations, and the two changes were entirely uncorrelated ($r=0$). There is increasing evidence across domains that changes in implicit and explicit cognitions can occur independently (Gawronski and Bodenhausen, 2006). These findings, together with the increasing recognition of the importance of more implicit processes in addictive behaviors, has lead researchers to begin to study whether it is possible to more directly change implicit appetitive processes (see Wiers et al., 2006b).

One approach currently tested uses varieties of "attentional retraining". In this approach, tests used to assess an attentional bias (e.g., drug-Stroop or Visual probe task) are adapted to train attention away from the drug-related stimulus. For example, in a normal visual probe task, the target replaces the alcohol picture in half of the cases. In a retraining version, the target replaces the neutral picture in almost all of the cases. In this way, the alcohol abuser implicitly learns to turn attention away from alcohol. Initial findings from three different labs are quite promising (Field and Eastwood, 2005; Wiers et al., 2006b). A second approach is to try to automatize action plans that lead to alternative behaviors instead of drug use. When stated in simple "if–then" formulations ("implementation intentions"), these action plans can lead to action without the need for controlled processes. An example could be: "When I drive, I drink soft-drink". Given the negative effects of many drugs on controlled processes, this may be particularly helpful in helping people to moderate their use of alcohol and drugs (see Palfai, 2006; Prestwich et al., 2006; Wiers et al., 2006b; Wiers and Stacy, 2006).

8. Conclusions and issues for further research

From the present perspective, the development of addictive behaviors in adolescence goes through different phases. In the first phase the individual is still able to regulate cue-induced appetitive motivational tendencies, but is not motivated to do so. In later phases, once enough alcohol- or drug-related problems are experienced, the individual may be more motivated to regulate appetitive inclinations. However, at this point, the ability to do so is compromised, due to two effects of chronic alcohol use: a stronger (sensitized) appetitive response and a weaker ability to regulate this response inclination. We believe the imbalance between these processes is at the core of addictive behaviors in adolescents, as far as intra-individual processes are concerned. However, in later phases of addiction (which may sometimes occur already in adolescence), other processes may become more important, such as automatic habitual responses (e.g., Everitt and Robins, 2005; Hogarth et al., 2005; Kalivas and Volkow, 2005) and negative reinforcement (e.g., Koob and La Moal, 1997; Baker et al., 2004). We emphasize that the present model focuses on the early stages of the addiction process, most common during adolescence, in which beginning use may or may not develop into problem-use. Whether in later stages a sensitized psychomotor stimulant reaction is still crucial in the maintenance of addiction (Robinson and Berridge, 1993, 2003) or whether at that point compulsive habitual responses are more important (Everitt and Robins, 2005; Hogarth et al., 2005; Kalivas and Volkow, 2005) is an issue of controversy, mainly based on animal research (but see Mogg et al., 2005, for a study in human adults relating to this discussion). Further, even though the focus in this review has been on intra-individual processes, it is important to consider that interpersonal processes are also crucial in the understanding of adolescent alcohol and drug use. Clearly, more (longitudinal) research is needed to study the interplay between the different processes in the development of addictive behaviors in adolescents. Combining the recently developed assessment tools to study the automatic implicit processes in addictive behaviors with measures of different types of executive control over these processes seems important. Adding neurocognitive measures may be particularly helpful in bridging the gap between human and animal research on alcohol and drug use in adolescents. In addition, social interactions can be studied experimentally in a controlled manner (e.g., Bot et al., 2005a), which will help to critically test predictive models of adolescent addictive behaviors. Finally, given the size and impact of the problem of adolescent alcohol and drug abuse, testing interventions aimed at this specific population are much needed.

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